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# Micro-structures of some Australian Termite nests

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With 25 figures

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## 1. Introduction

Wood and Lee (1971) have discussed the distribution of some Australian termite species and also (Lee and Wood 1971b) their physical and chemical effects on soils. The same authors (Lee and Wood 1971a) also briefly discussed the macromorphology and micromorphology of mounds and other structures in relation to building behaviour of the termites. In this paper emphasis is placed on classification of the materials found in various parts of nests of the different species.

Previous observations on the micro-structure of the nests of termites have been made by Gennart et al. (1961) and Stoops (1964). The latter introduced three special terms to describe specific structures in nests viz pellet-structure, bow-structure and lamellar-structure.

Whilst there are differences in building behaviour of various families and genera of termites, the behaviour is remarkably similar in widely differing genera. Basically a nymph or worker carries debris or a dry faecal pellet in the mandibles to the site of deposition (where the former may be remoulded with saliva as cement), places a spot of faecal cement on the site and then places the debris or pellet on the cement (Stuart 1969). However it appears that the use of dry faecal pellets is restricted to a few groups of termites, none of which are included in the present study (Lee, personal communication). The wide variety of micro-structures observed in this present study is compatible with the different methods of construction observed by previous authors (e.g. Emerson 1938), and discussed by Lee and Wood (1971a).

## 2. Materials and methods

Sixty thin-sections (6 × 5 cm) were prepared from undisturbed samples of nests of 14 species of termites from 18 different sites throughout Northern Territory, Queensland and New South Wales (Australia). The list of species and descriptions of sample sites follows that given by Lee and Wood (1971b) in their Table 1 and Appendix with the exceptions that no samples were taken from nests of *Schedorhinotermes intermedius actuosus*, *Nasutitermes longipennis* and *Tumulitermes*

1a

*comatus* and further, no samples were taken from site number 17. Most of the samples were taken from mounds and where these were differentiated each region (nursery, inner and outer region, soil cap, etc.) was sampled but that for *Mastotermes darwiniensis* was taken from a nest in the wall of a shed and those from *Amitermes* sp. and *Porotermes adamsoni* (sample supplied by T. GREAVES) from nests in standing trees.

The thin-sections were prepared by the normal method, following impregnation with the polyester resin Plastrene 51 with cyclohexanone peroxide as catalyst, cobalt naphthanate as accelerator and acrylic monomer (cresol stabilized) as diluent. The descriptions basically follow the system proposed by BREWER (1964) but for the sake of brevity certain recurring fabric features have been defined.

## 3. Micro-structures

### 3.0. Prefatory note

Within the materials examined there is a wide range of micro-structures which require some form of grouping for concise description. Whilst many groupings are possible depending on the requirements of the classification and the characteristics chosen, here most weight is given to those characteristics which are considered to reflect the processes of construction of the nest. As found by SIDDIQUI (1964) previously, descriptions can be made clearer if certain recurring fabric features are initially defined.

### 3.1. Micromorphological features

#### *3.1.1. Organic laminae*

Thin organic laminae are developed to varying degrees in all the materials examined with the exception of *Porotermes adamsoni*, the soil cap material from a mound of *Nasutitermes exitiosus* and the subterranean galleries of *Tumulitermes hastilis*. These laminae tend to be clustered or banded adjacent to present gallery walls or within gallery fills, they have sharp boundaries and appear to fall into two rather vague groups as far as composition is concerned, viz:

Type A — dark brown to reddish brown isotropic to very weakly anisotropic organic material (in thin-section) occurring as bands 5—60 $\mu$m wide (most commonly 20—30 $\mu$m, and sometimes fragmented, Figs. 1a and b); and

1b

Figure 1. Type A (dark brown to reddish brown isotropic to very weakly anisotropic) organic lamina. *Drepanotermes rubriceps* — gallery wall from outer mound. Frame length 0.34 mm. (1a) Plain light, (1b) under crossed polarizers.

Type B — pale brown to pale reddish organic material, strongly anisotropic in part (under crossed polarizers appears to consist of small anisotropic fibres, up to 30 $\mu$m long in an isotropic ground mass), occurring in bands 20—300 $\mu$m wide (most commonly 120 $\mu$m, Figs. 2a and b). This material is identical with the s-matrix of much of the carton[1]) material.

### *3.1.2. Organic nodules*

Materials of the same composition as the organic laminae type A and B, either with or without included skeleton grains, may occur as equant, prolate or platy nodules in the size range of 10—400 $\mu$m (Figs. 9 and 10).

### *3.1.3. Pellets*

The pellets recognized in these materials are spheroidal or ovoid bodies in the size range 300—600 $\mu$m composed of organic material, mineral soil material or various combinations of both. Pellets have been recognized as units occurring singly (Figs. 12 and 25), welded (Figs. 13a and b), or somewhat flattened (Fig. 14) in gallery fills and also within structural walls (Figs. 15a and b). Their prior existence in a material has been inferred from the presence of rounded or mammillated voids (Figs. 16a and b) and lenticular fabric; in the latter, adjacent lenses of soil material frequently have different mechanical compositions (i.e. high and low proportions of plasma, Fig. 4) or colour.

The origin of these various pellets is discussed later, but it is certain that many of the smaller single pellets occurring in present galleries are micro-arthropod droppings; those depicted in Figure 12 are most likely droppings of millipedes that invaded the mound to feed on stored grass. On the other hand the larger pellets occurring within structural

1) Carton consists largely of the excreta of termites formed into a labyrinth of laminar or alveolar structure making up the galleries of the central portion of the mound and nest of many species of termite.

Table 1 Micromorphological classes of nest materials examined

| Class | Voids | | S-matrix Organic Compos. | | Organic Laminae | | | | | Org. Nod. Composit. | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Composit. | | Fabric | | | | |
| | Skew Planes | Vughs | A | B | A | B | Lent. | Lam. | Cren. | A | B |
| Ia | | F | | F/C | | | | | | F* | |
| | C | VR | | F/C | | + | | | | F* | |
| Ib | C | O | | C | | F | | S | | F/C* | |
| | F | | | F | | F | | S | | F* | |
| Ib–c | C | | | F | C* | | VW | M | | C/F* | |
| Ic | C/F | | | F | F* | | S | S | | F* | |
| Id | VR | VR | | O | | C | | | W | | |
| | VR | VR | | O | | C | | | W | | |
| | F | | | F | | F | | | S/M | O/R* | |
| IIa | VR | | | | F | | S | | | | |
| | O | O | | | F | | S | | | R | |
| | O | O | | | F | | S | | | R | |
| | VR | R | | | F | | M/S | | | C | |
| | VR | R | | | F | | M/S | | | C/F | |
| | | R | | | F | | S/M | | S | F | |
| IIav | | O | | | O | | M/W | | | O | |
| | | O | | | O | | M/W | | | O | |
| | | O/R | | | F | | S | | | F | |
| IIa–c | C | O/R | | | F | | M | | | | |
| IIb | | C/F | | | O | | VW | | | R | |
| | | F | | | | C/F | W | | | | F |
| | | F | | | | | | | | | F |
| | | F | | | | O | W | | | | C |
| IIbc | R | O/C | | | | R | | | | | R |
| IIc | | O | | | VR | | | | | VR | |
| | O | C | | | VR | | | | | R | |
| | | R | | | | | | | | + | |
| IIcv | R | + | | | R | | VW | | | + | |
| | R | + | | | R | | VW | | | + | |
| | O/C | + | | | R | | VW | | | + | |
| IIIa | VR | R | + | | O | | W/M | | W/M | C/F | |
| | VR | R | + | | O | | W/M | | W/M | C/F | |
| | C/O | R | + | | O/C | | W/M | | VW | C | |
| IIIav | VR | VR | + | | R | | VW | VW | | | |
| | VR | VR | + | | R | | VW | VW | | | |
| IIIb | R | C | | C | | C | | S | S | | C |
| | C | R | | C | | C | S | S | | | |

Frequency estimates F = frequent, C = common, O = occasional, R = rare, VR = very rare,
Degree of development of fabric S = strong, M = medium, W = weak, VW = very weak.
Soil material nature A = skeleton grains, B = skeleton grains + clay plasma, C = skeleton
Principal food – (1) Dead wood, (2) Living and dead wood, (3) Grass.
Pellets – Only those within structural gallery walls. Probable origin – (a) anal, (o) oral.
* Reddish isotropic – approaching type B organic matter.

walls and as dense gallery fills, are more likely to be a product of termite activity (either anal or oral) and therefore have been given greater emphasis in Table 1.

### *3.1.4. Lenticular fabric*

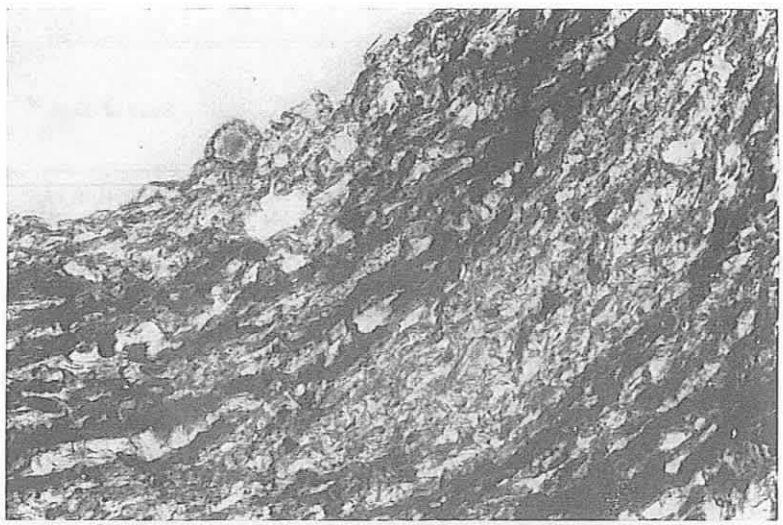
The organic laminae, particularly type A, may occur singly, each successive lamina cutting off lens-shaped nodules of soil material 0.2–0.4 mm thick producing what will be referred to as lenticular fabric (Fig. 3). This fabric is sometimes developed within walls

| Bow Struct. | Pellet | Soil Mat. Nat. | Species | | Part of Nest |
|---|---|---|---|---|---|
| | F (a) | | *Porotermes adamsoni* | (2) | Mudgut in tree |
| | R (a) | | *Mastotermes darwiniensis* | (1) | Carton in wall of shed |
| | | | *Coptptermes lacteus* | (1) | Nursery, inner, outer moud |
| | C (a) | | *C. lacteus* | (1) | Outer mound |
| | C (a) | | *C. lacteus* | (1) | Nursery, inner mound |
| | F (a) | | *Coptotermes acinaciformis* | (2) | Carton |
| | | | *Nasutitermes magnus* | (3) | Nursery |
| | | | *N. exitiosus* | (1) | Nursery |
| | | | *N. exitiosus* | (1) | Nursery, inner mound |
| | | A | *Drepanotermes rubriceps* | (3) | Outer mound |
| | | A | *Nasutitermes triodiae* | (3) | Outer mound |
| | R (o) | A + B | *Amitermes laurensis* | (3) | Outer mound |
| | VR (o) | A/B | *Nasutitermes triodiae* | (3) | Outer mound |
| | | A or B | *Amitermes laurensis* | ((3) | Outer mound, hard core |
| | | A | *Tumulitermes pastinator* | (3) | Nursery, outer mound |
| | | B | *Coptotermes acinaciformis* | (2) | Soil cap |
| | | A | *Nasutitermes triodiae* | (3) | Hard basal portion mound |
| | | B | *N. triodiae* | (3) | Hard core mound |
| | | B | *N. triodiae* | (3) | Outer mound |
| | R (o) | A + B | *Nasutitermes magnus* | (3) | Outer mound |
| | C/F (o) | B | *Nasutitermes exitiosus* | (1) | Outer mound, soil cap |
| | C/F (o) | B | *Nasutitermes oxitiosus* | (1) | Soil cap |
| | C/F (o) | B | *Coptotermes lacteus* | (1) | Soil cap |
| | VR (o) | C | *Coptotermes lacteus* | (1) | Soil cap |
| M/S | | A | *Drepanotermes rubriceps* | (3) | Subterranean galleries |
| | | B | *Nasutitermes magnus* | (3) | Outer mound |
| | | B | *Tumulitermes hastilis* | (3) | Subterranean galleries |
| | | B | *Tumulitermes hastilis* | (3) | Outer mound |
| | | B | *Amitermes vitiosus* | (3) | Outer mound |
| | | B | *Coptotermes acinaciformis* | (2) | Soil cap |
| | | A + B | *Nasutitermes triodiae* | (3) | Nursery |
| | | A + B | *N. magnus* | (3) | Nursery |
| | | A | *Amitermes meridionalis* | (3) | Top of mound |
| VW | | A | *Amitermes meridionalis* | (3) | Hard core mound |
| VW | | B | *Amitermes* sp. | (1) | Galleries under bark |
| | | A + B | *Nasutitermes exitiosus* | (1) | Outer mound |
| | | B | *Microcerotermes nervosus* | (2) | Outer mound |

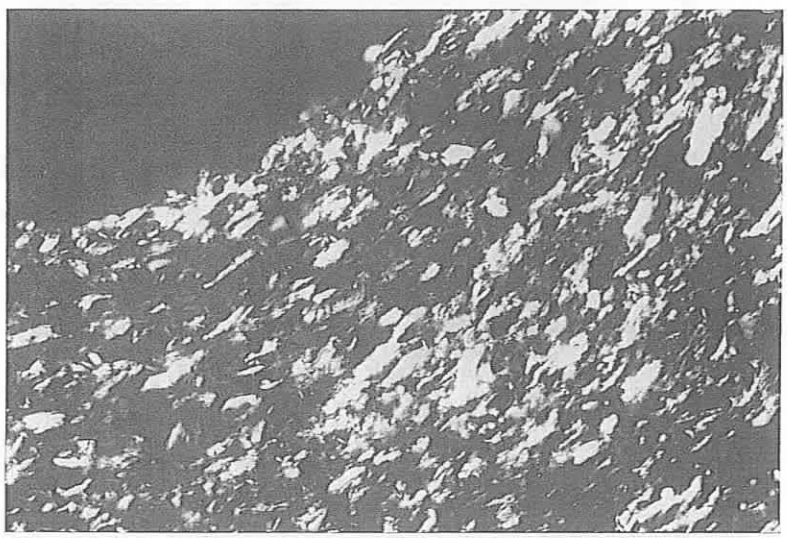
+ = present.

grains incl. weatherable minerals.

of galleries but may also be associated with more recent gallery fill, with a strong semi-elliptical arrangement, and is most strongly developed in those materials which are dominantly soil (skeleton grains, clay-mineral plasma and pedological features) with little organic matter. Frequently adjacent lens-shaped nodules of soil material have different proportions of clay-mineral plasma, i.e. the pellets from which lenticular fabric has been constructed consist of different soil materials with high and low proportions of clay-mineral plasma (Fig. 4).



2a



2b

Figure 2. Type B (pale brown to pale reddish, strongly anisotropic) organic laminae. *Microcerotermes nervosus* — gallery wall from outer mound. Frame length 0.34 mm. (2a) Plain light (2b) under crossed polarizers.

### *3.1.5. Lamellar and crenulate fabric*

Alternatively, organic laminae, particularly type B, may occur in parallel groups producing a lamellar (or even convolute — BREWER 1964) fabric (Fig. 5) when smoothly parallel, or a crenulate fabric (Fig. 6) when wavy on a small scale. A parallel arrangement may be revealed by the nature of the cracks (see STOOPS 1964 and Fig. 7), the orientation within the laminae or slight changes in composition (Fig. 5). Lamellar gallery linings may be associated with lenticular fabric within structural walls as shown in Figures 8a and b.

Figure 3. Lenticular fabric in which type A organic laminae surround lens – shaped nodules of soil material. *Drepanotermes rubriceps* – gallery wall from outer mound. Frame length 3.35 mm. Plain light.

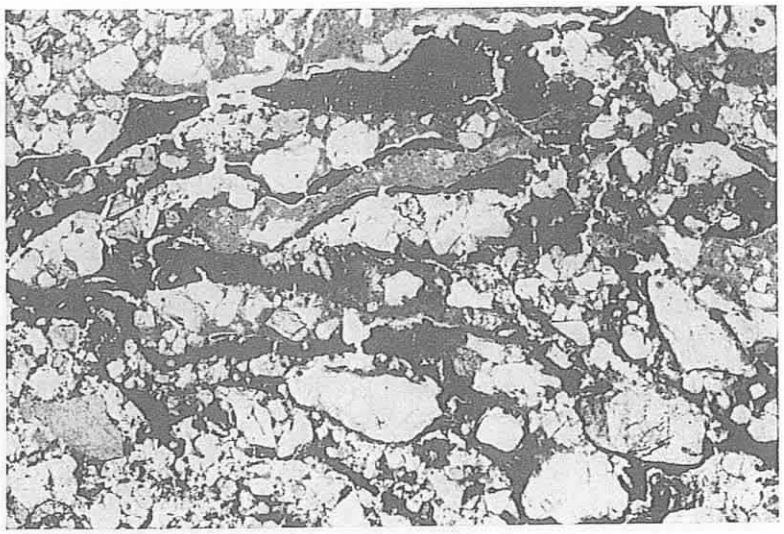


Figure 4. Lenticular fabric incorporating soil nodules with a high proportion (grey areas) and a low proportion (white areas) of clay-mineral plasma. *Nasutitermes triodiae* – hard core of mound. Frame length 3.35 mm. Plain light.

### *3.1.6. Bow-structure* (Stoops 1964)

In the materials examined, bow-structure is produced by vague rather diffuse laminae and nodules of organic matter and in fact approaches a lamellar fabric as defined by variable concentrations of organic matter (Fig. 11). It is mainly confined to materials with high proportions of medium-sized skeleton grains, low proportions of organic plamsa and lacking clay-mineral plasma.

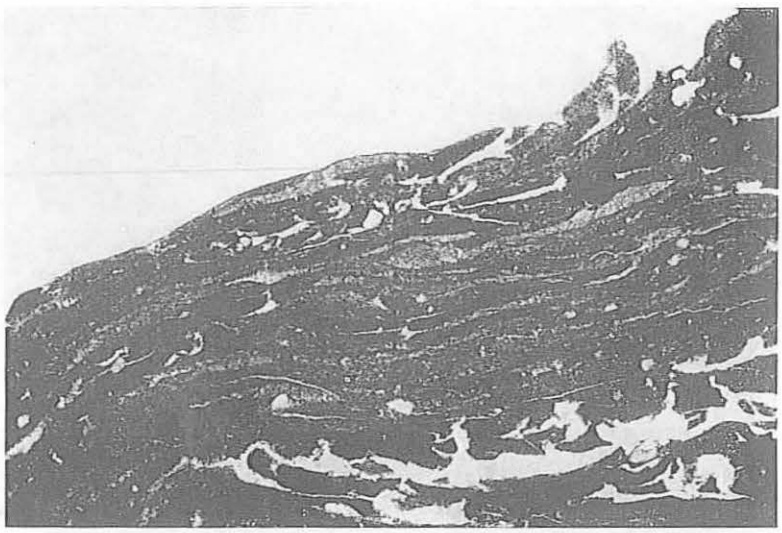


Figure 5. Lamellar fabric in which the parallel arrangement is revealed by slight changes in composition of successive type B organic laminae. *Coptotermes lacteus* — gallery wall from outer mound. Frame length 3.35 mm. Plain light.

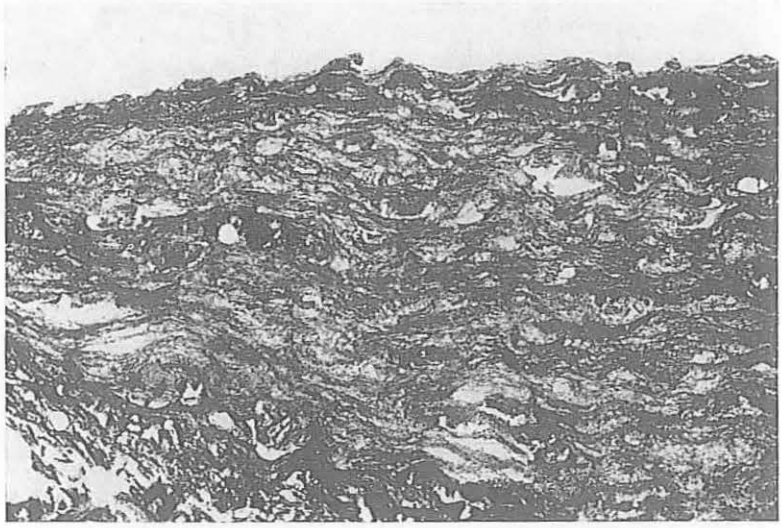


Figure 6. Crenulate fabric in type B organic laminae. *Nasutitermes exitiosus* — soil cap of abandoned mound. Frame length 3.35 mm. Plain light.

## 3.2. Classification groups

### *3.2.0. Prefatory note*

Three major classes of nest materials are distinguished on the composition of the construction material, viz. dominantly organic material, dominantly soil material, and organic plasma with frequent skeleton grains and variable proportions of soil material. Within each of these, subclasses are distinguished on void patterns (voids other than galleries)

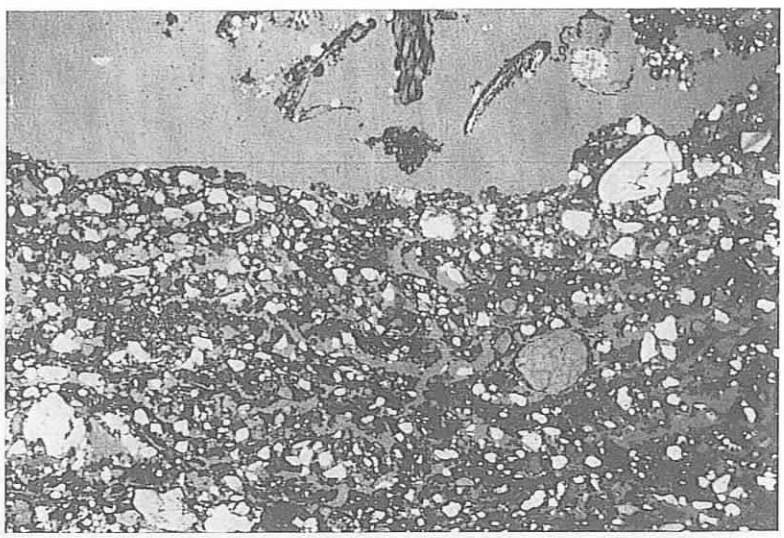


Figure 7. Lamellar fabric in which the parallel arrangement is associated with planar voids. *Amitermes meridionalis* — gallery wall from top of mound. Polarizers incompletely crossed. Frame length 3.35 mm.

and the degree of development and arrangement of the micro-structural features and fabrics described above. However, intergrades between these classes do occur and it is possible that an increased number of samples would reveal a continuum between samples.

Table 1 summarizes the micromorphology of the examined nest materials in the above terms with additional information on the composition of the soil material used in construction, viz. A, dominantly skeleton grains; B, skeleton grains and clay-mineral plasma; and C, dominantly skeleton grains with a high proportion of weatherable minerals. The frequency class estimates of organic composition of the s-matrix refer specifically to organic fibres visible under crossed polarizers. The frequency estimates of pellets refer to those occurring within the gallery walls[1]) and are qualified as to their most likely origin, viz. anal (a) or oral (o). Table 2 summarizes the micromorphological classification of materials from the various regions of nests of the various species.

### *3.2.1. Class I*

*3.2.1.0. General remarks*

Dominantly type B organic material with very rare skeleton grains; the size of the skeleton grains varies widely between samples; the skeleton grains may be clustered, especially in areas away from the galleries; the voids are mainly short skew planes (Figs. 17 and 18).

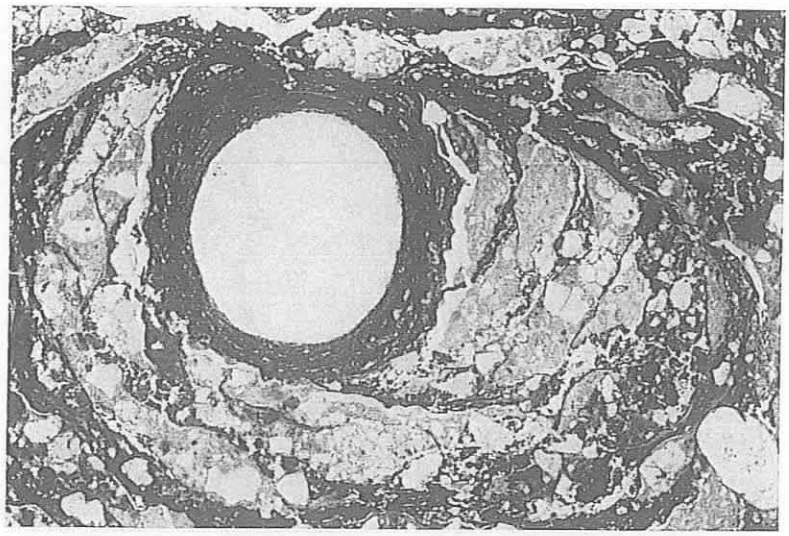
Variations between samples in class I are due mainly to the frequency and degree of preservation (distinctness) of pellets, and the pattern of distribution of the organic laminae, viz. lenticular, lamellar, crenulate or lack of same (undifferentiated).

*3.2.1.1. Class Ia*

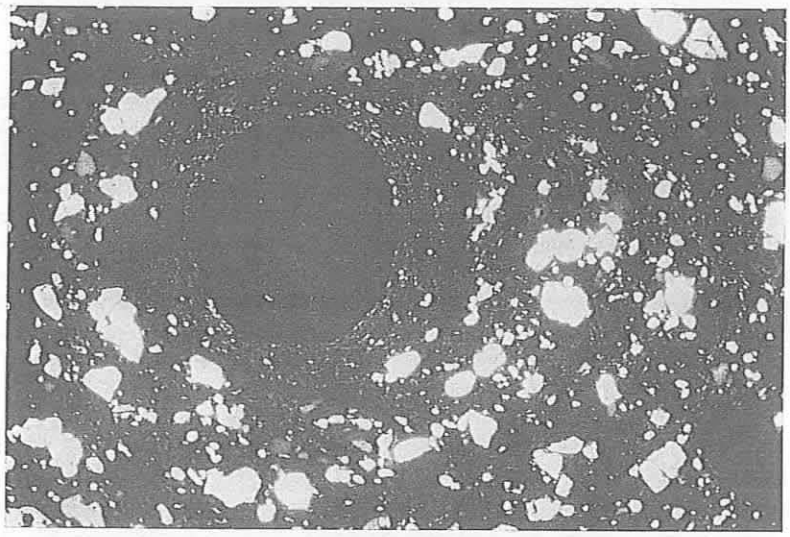
Composition: Small anisotropic organic fibres in an isotropic organic groundmass.

Fabric: The material is dense with short, often curved skew planes; some voids may be mammillated, Essentially isotic plasmic fabric with anisotropic organic fibres randomly

1) Gallery wall as used here refers to all the material between two adjacent galleries.



8a



8b

Figure 8. Lenticular (gallery wall material) and lamellar fabric (gallery lining). *Microcerotermes nervosus* — gallery and wall material from outer mound. Frame length 3.35 mm, (8a) Plain light (8b) under crossed polarizers.

oriented in the groundmass. Laminae are very rare, faint thin and reddish with a concentration of small red organic nodules. Pellets are generally not recognizable except as mammillated walls to a few voids.

Species and variants: *Mastotermes darwiniensis* carton. *Porotermes adamsoni* mud-gut material, with distinct anal pellets of type B organic material, approximately 500 $\mu$m in diameter and occasional black pear-shaped spores 50 $\mu$m in diameter, lacking organic laminae; the voids are largely simple packing voids (Fig. 25).

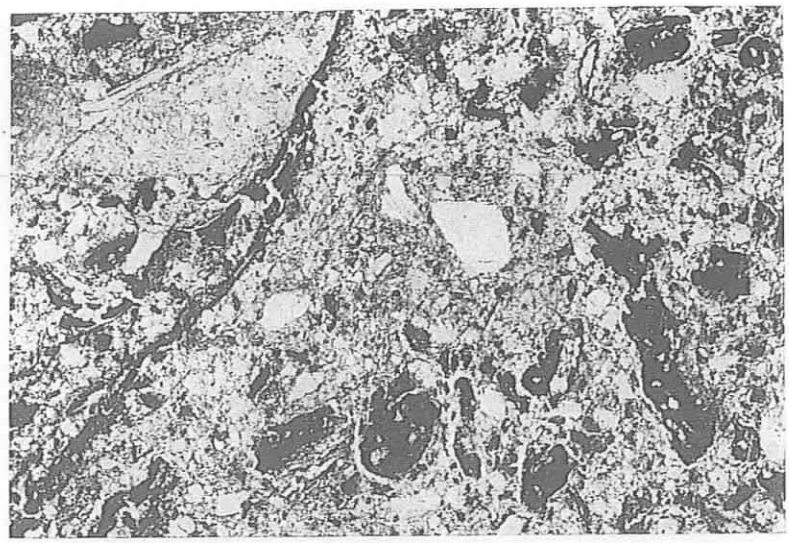


Figure 9. Type A organic nodules, with included skeleton grains, occurring within the s-matrix of gallery wall. *Tumulitermes pastinator* — gallery wall from outer mound. Frame length 3.35 mm. Plain light.

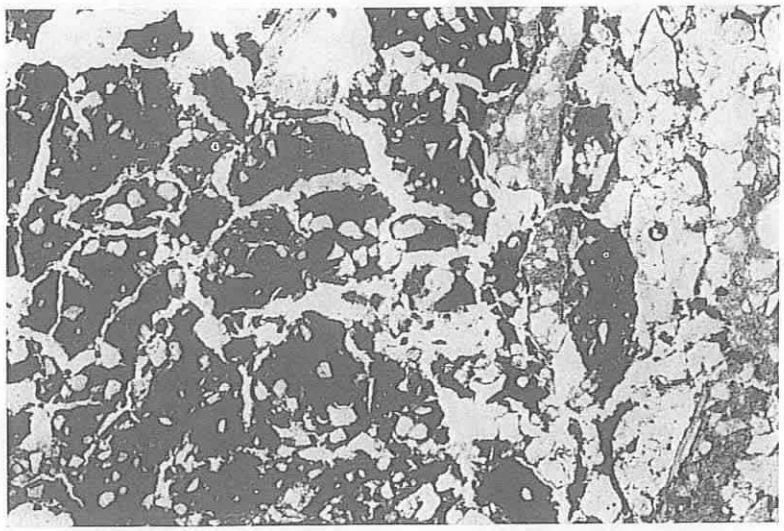


Figure 10. Type A organic nodules, with included skeleton grains, occurring as gallery fill (dark area to left). *Nasutitermes triodiae* — hard core of mound. Frame length 3.35 mm. Plain light.

*3.2.1.2. Class Ib*

Composition: As for class Ia, but in addition may have very rare nodules and/or laminae of soil material.

Fabric: The material is dense with short, often curved skew planes; some voids may be mammillated. There are frequent very fine organic nodules of type A. Frequent fine,

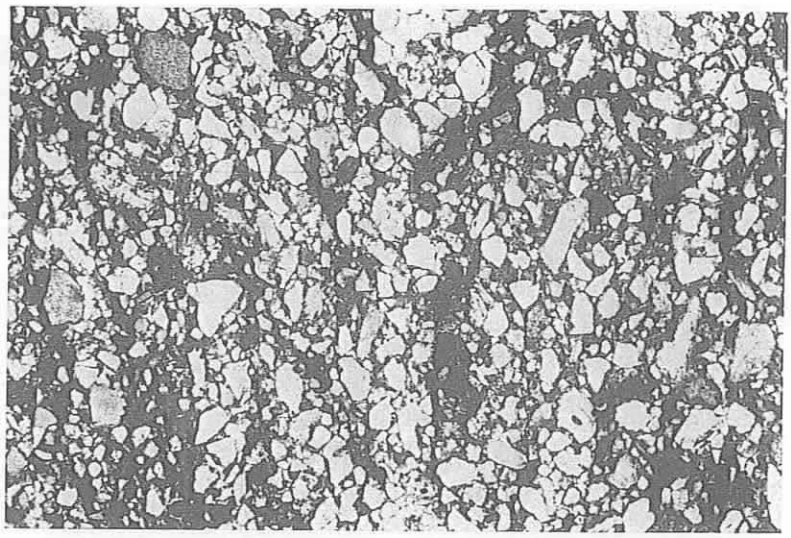


Figure 11. Bow-structure (Stoops 1964). *Drepanotermes rubriceps* — subterranean gallery wall of slab-type nest. Frame length 3.35 mm. Plain light.

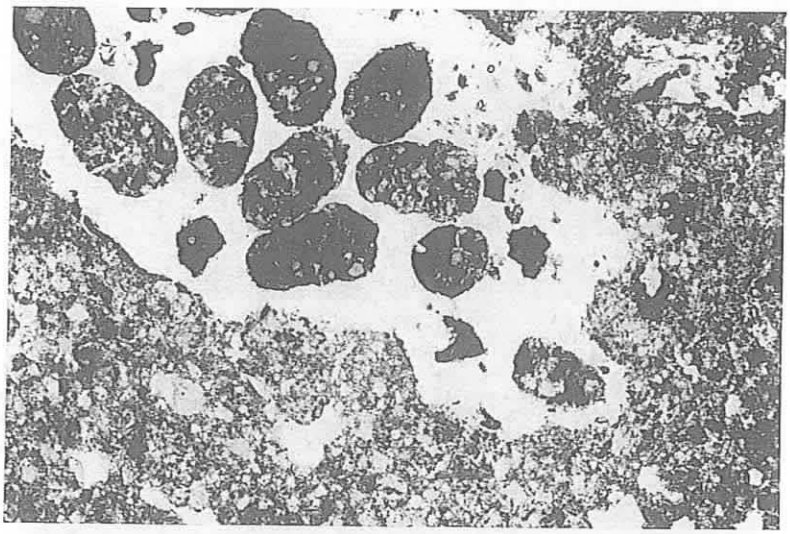
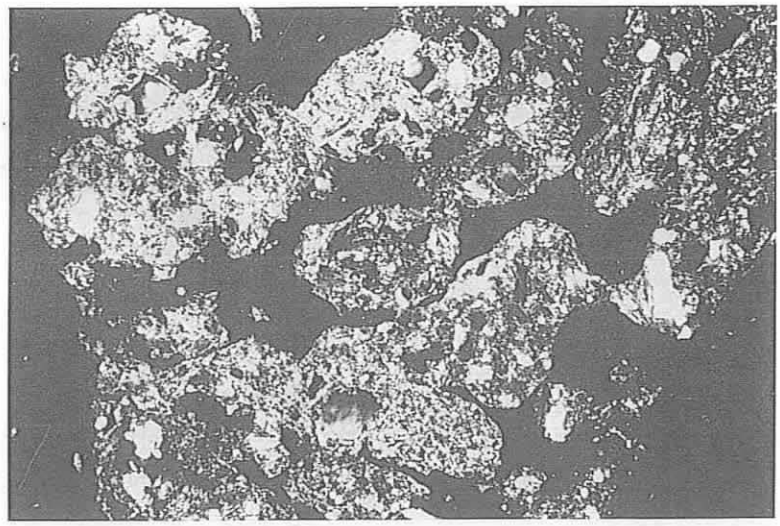
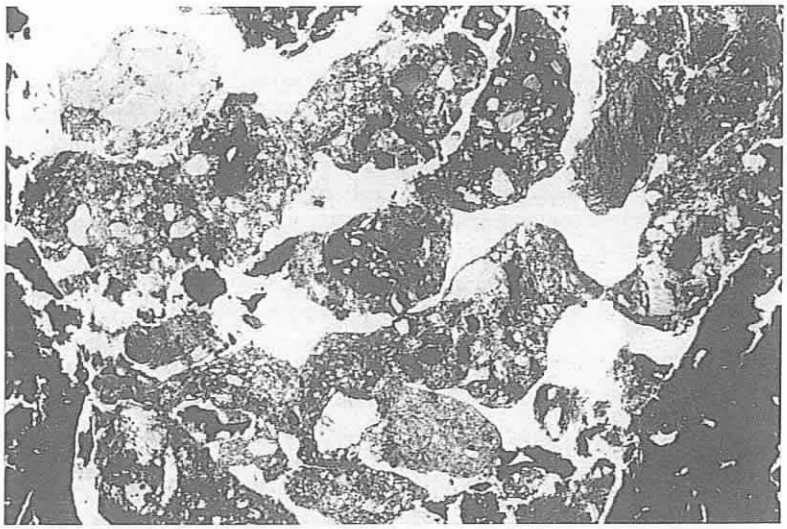


Figure 12. Single pellets (probably millipede droppings) within gallery. *Amitermes laurensis* — hard core of mound. Frame length 3.35 mm. Plain light.

closely spaced reddish brown type B organic laminae occur throughout and type A laminae are relatively rare. Lenticular fabric is generally absent (very weak in some areas); laminae are so fine and closely spaced that they are essentially parallel giving lamellar, unistrial fabric due to alignment of organic fibres; the laminae may be highly contorted, approaching the convolute fabric of Brewer (1964). Pellets are very rarely recognizable and consist of type B organic material most likely of anal origin; see Figure 17.



13a



13b

Figure 13. Welded pellets within gallery. *Nasutitermes exitiosus* — gallery from outer region of abandoned mound. Frame length 3.35 mm. (13a) Plain light, (13b) under crossed polarizers

Species and variants: *Coptotermes lacteus* nursery, inner and outer mound. Some have common pellets in the structural gallery walls, and some samples from the nursery and inner mound are intermediate between classes Ib and Ic as they have type A organic laminae with a weaker lamellar fabric intergrading to lenticular fabric.

*3.2.1.3. Class Ic*

Composition: Very frequent large anisotropic fibres with a relatively small proportion of isotropic organic groundmass; the fibres are recognizable in plain light.

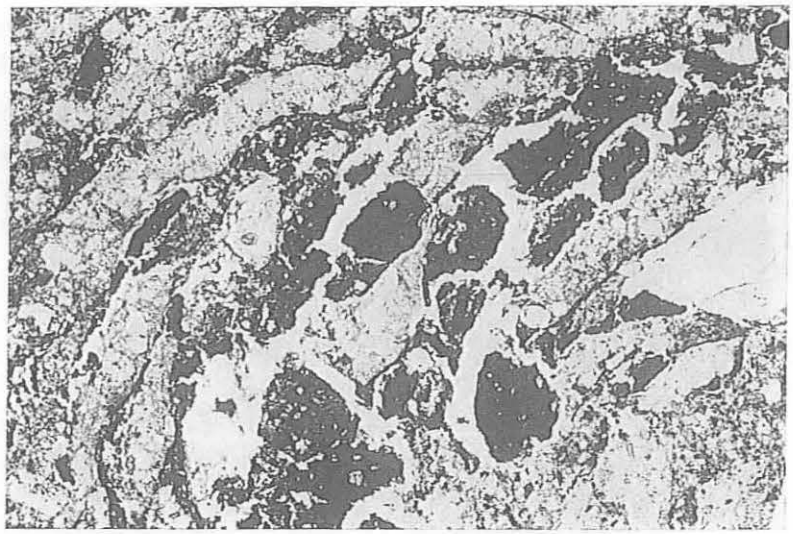


Figure 14. Flattened pellets (black anal, grey oral?) in gallery fill. *Amitermes laurensis* — gallery wall from outer mound. Frame length 3.35 mm. Plain light.

Fabric: The material is dense with short, often curved skew planes. There are frequent organic nodules of type A. Frequent isotropic reddish brown type A organic laminae (intergrading to type B laminae) occur both near the galleries and throughout the mass. Lenticular and lamellar fabric are strongly developed throughout the mass. The material has an overall mottled appearance due to packing of very frequent distinct yet distorted pale and reddish pellets that are isotropic in part but approach type B organic matter, probably of anal origin.

Species: *Coptotermes acinaciformis* carton.

*3.2.1.4. Class Id*

Composition: As for class Ia.

Fabric: More porous than other class I materials. Laminae are essentially as for class Ib except that they have a strong to moderate crenulate fabric giving rise to irregular vughs and short irregular skew planes. There are occasional to rare organic nodules of type A. Pellets are indistinct and not generally recognizable. See Figure 18.

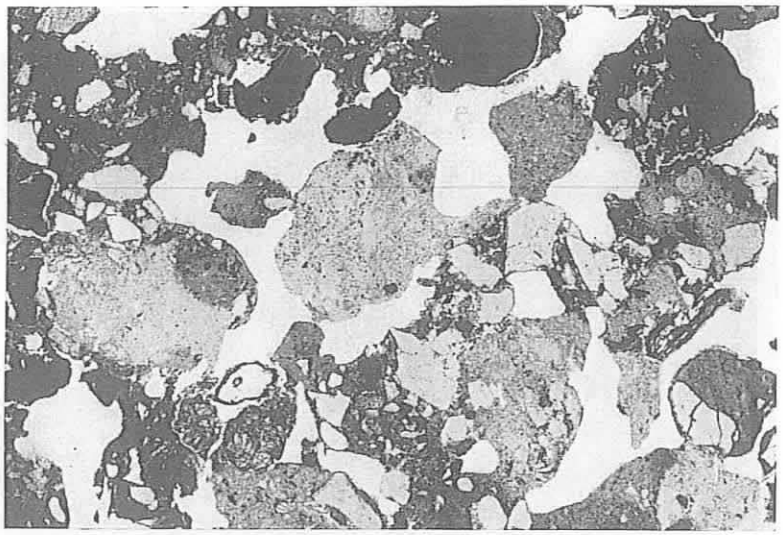
Species and variants: *Nasutitermes exitiosus* nursery and inner mound. *Nasutitermes magnus* nursery. The nursery material of *Nasutitermes magnus* has a weaker crenulate fabric and contains frequent secondary silica bodies (opal phytoliths?).

### *3.2.2. Class II*

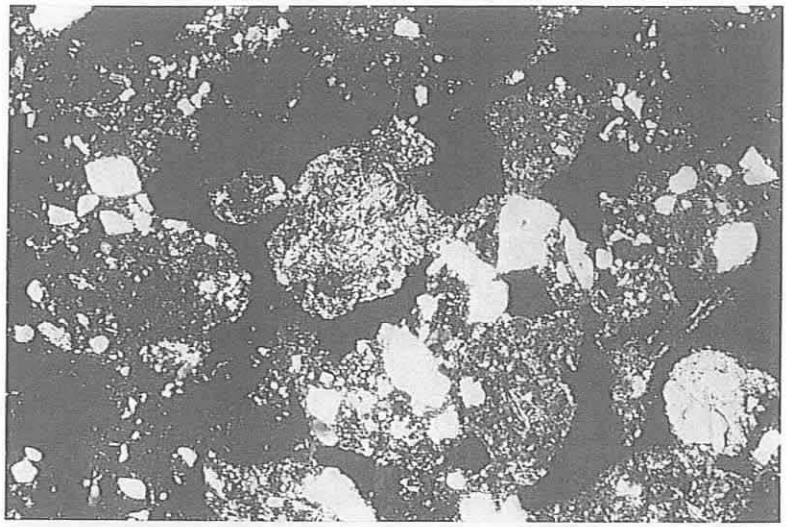
*3.2.2.0. General remarks*

Dominantly soil material (skeleton grains, clay-mineral plasma and pedogenous features) with a little organic matter that occurs dominantly as type A laminae and nodules (Figs. 19—22).

Variations between samples in class II are again mainly due to the frequency and thickness of the organic laminae, the degree of development of lenticular fabric, the frequency of large vughs, and the dominant kind of soil material used in the construction, i.e. soil material A or B (see legend for Table 1).



15a



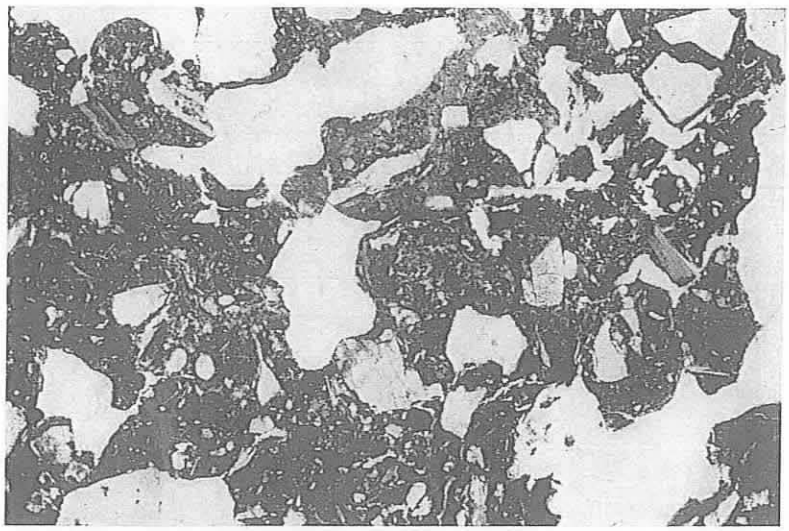
15b

Figure 15. Pellets of soil material within structural walls of mound. *Nasutitermes exitiosus* — soil cap. Frame length 3.35 mm. (15a) Plain light, (15b) under crossed polarizers.

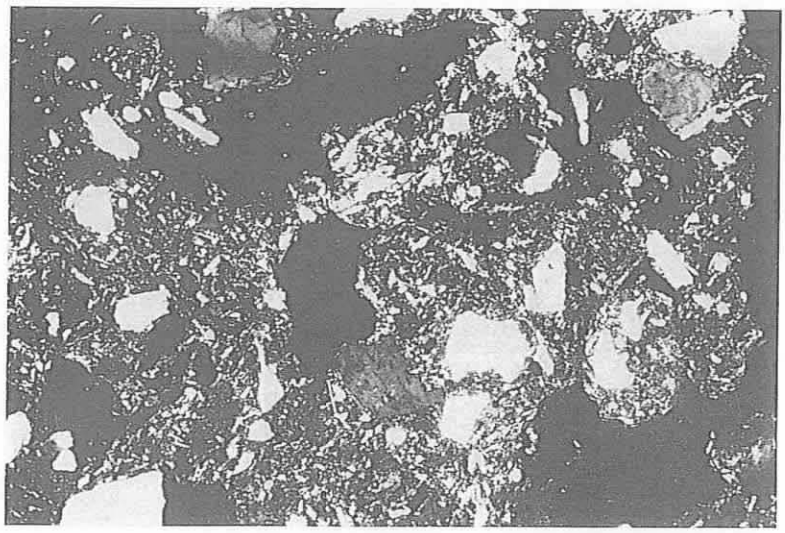
*3.2.2.1. Class IIa*

Composition: Soil material (type A, i. e. with a low proportion of clay-mineral plasma) with a relatively low proportion of organic matter occurring as organic laminae and fine fibres.

Fabric: Relatively dense silasepic or masked (organic) argillasepic porphyroskelic fabric, with variable frequency of skew planes and vughs (usually rare to occasional, and in certain materials rounded). Dark brown type A organic laminae occur generally throughout the material; the laminae are usually thin in the mass of the material and thicker



16a



16b

Figure 16. Mammillated vughs in structural walls of mound. *Coptotermes lacteus* — new building on soil cap. Frame length 3.35 mm. (16a) Plain light, (16b) under crossed polarizers.

and more closely spaced towards the galleries or in gallery fills. Organic nodules of type A occur with variable frequency. Lenticular fabric is usually moderately to strongly developed, but is often confined to zones near galleries or in filled galleries. Pellets are recognizable as organic nodules associated with rather dense gallery fills and the distorted soil lens component of the lenticular fabric; the former are probably anal and the latter oral. See Figures 19 and 20.

Species and variants: *Drepanotermes rubriceps* outer mound, lacking organic nodules. *Tumulitermes pastinator* nursery and outer mound with strongly developed

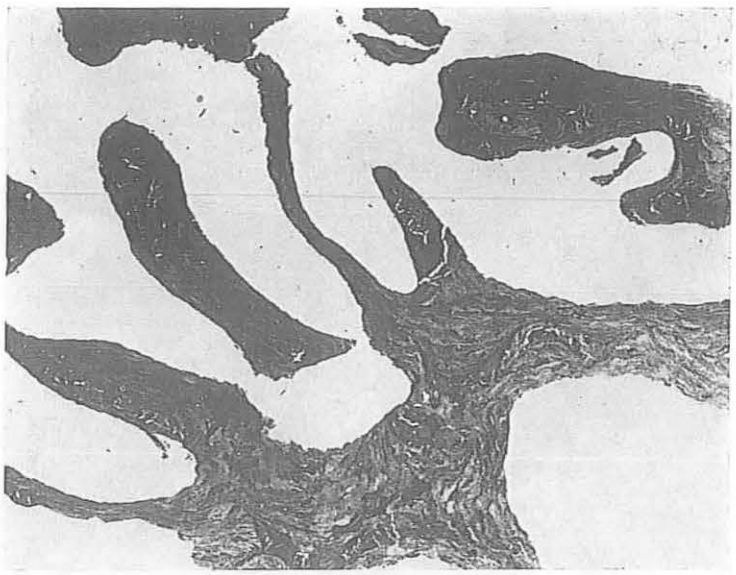


Figure 17. Class Ib material. Essentially frequent, fine closely-spaced, type B organic laminae with a lamellar unistrial fabric. *Coptotermes lacteus* — nursery. Frame length 4 cm. Plain light.

Figure 18. Class Id material. Essentially frequent, fine, closely-spaced, type B organic laminae with a crenulate fabric — here with a minor mineral soil component, *Nasutitermes exitiosus* — inner mound. Frame length 4 cm. Plain light.

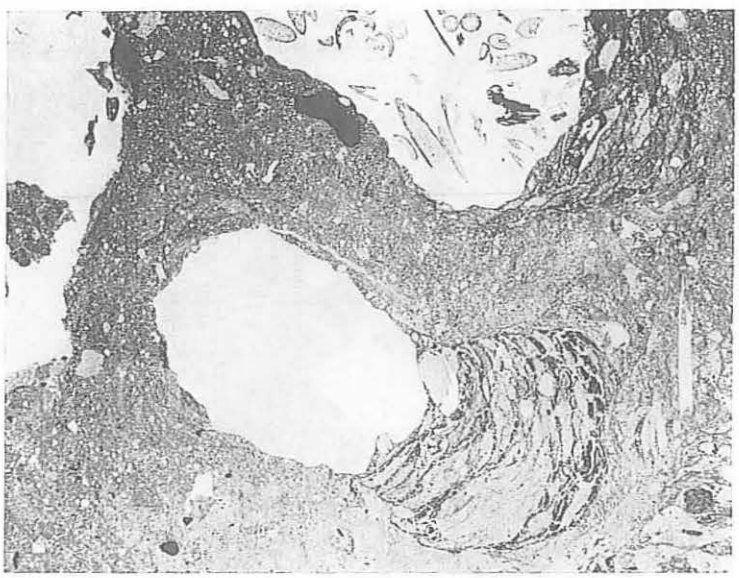


Figure 19. Class IIa material. Essentially relatively dense mineral soil material with thin, type A organic laminae and moderately to strongly developed lenticular fabric. *Drepanotermes rubriceps* — outer mound. Frame length 4 cm. Plain light.

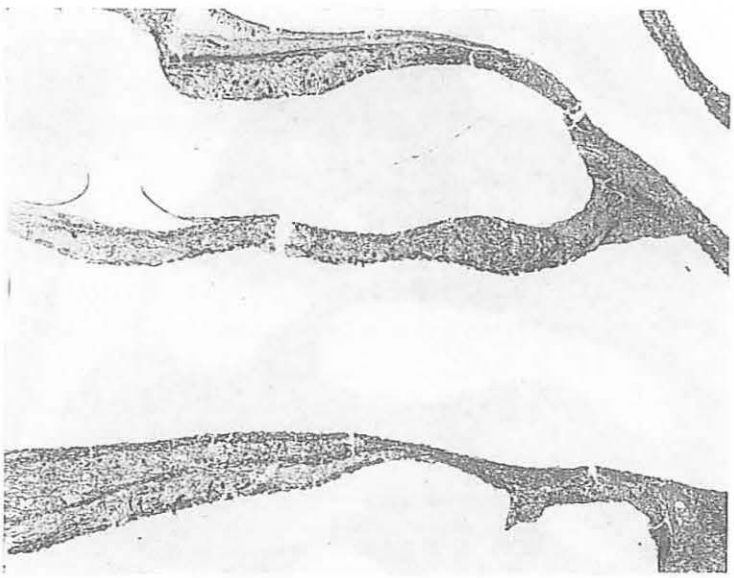


Figure 20. Class IIa material. As for Fig. 19 but here the organic laminae have a crenulate fabric. *Tumulitermes pastinator* — nursery chamber. Frame length 4 cm. Plain light.

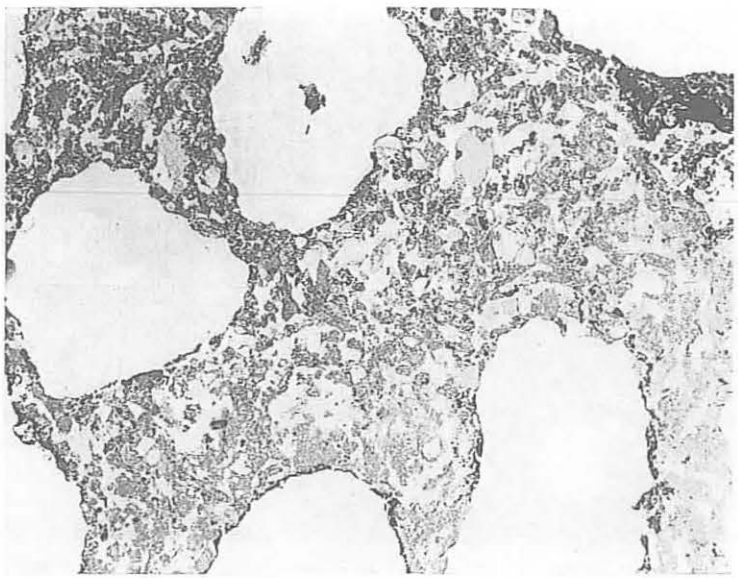


Figure 21 Class IIb material. Essentially very porous, type B mineral soil material with frequent pellets and organic nodules throughout. *Nasulitermes exitiosus* — outer mound. Frame length 4 cm. Plain light.

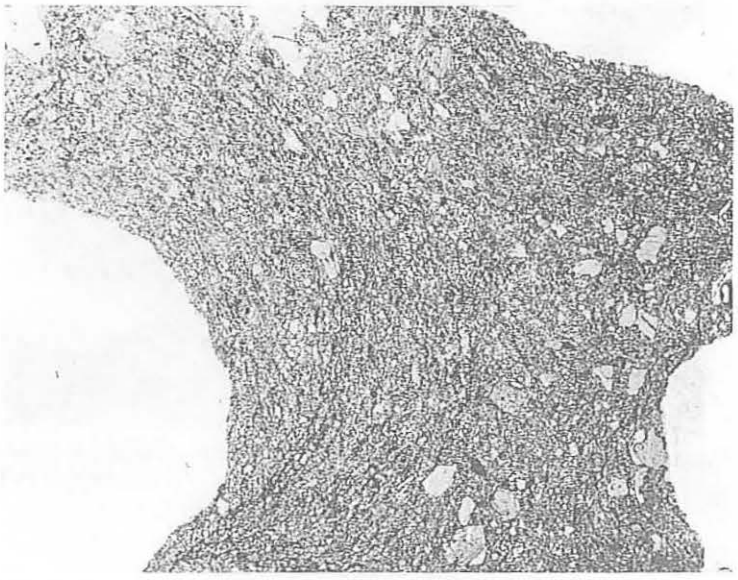


Figure 22. Class IIc material. Essentially mineral soil material with a low proportion of organic material occurring as rather diffuse, indistinct, broad laminae and/or nodules — c.f. bowstructure of Stoops (1964). *Drepanotermes rubriceps* — subterranean gallery wall of slab-type nest. Frame length 4 cm. Plain light.

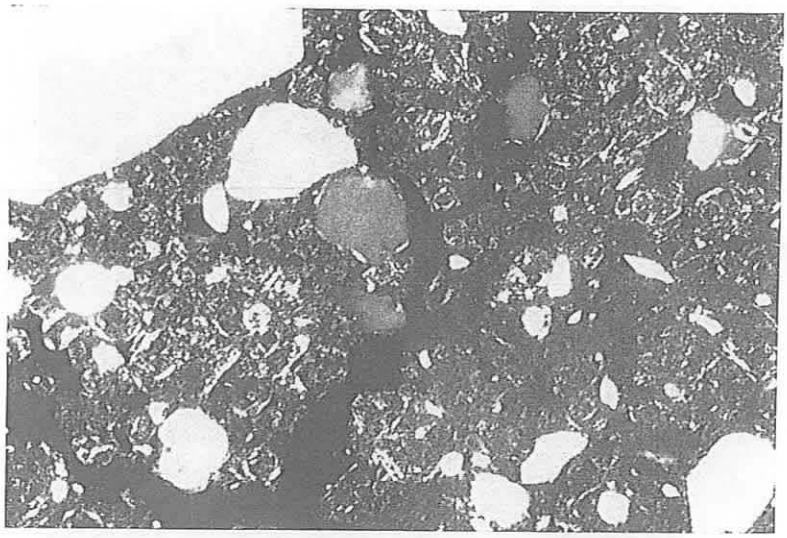


Figure 23. Spheroidal aggregates of mineral soil material revealed under crossed polarizers. *Tumulitermes hastilis* — gallery wall of outer mound. Frame length 3.35 mm.

Figure 24. Class IIIb material. Essentially type B organic material with sub-dominant mineral soil material — here with lamellar fabric, lenticular fabric and single pellets in galleries. *Microcerotermes nervosus* — outer mound. Frame length 4 cm. Plain light.

crenulate fabric associated with gallery walls. *Amitermes laurensis* outer mound and hard core. A pair of samples from one *Amitermes laurensis* site lack opal phytoliths whilst another pair from a different site include flood amounts of opal phytoliths in the s-matrix; some outer mound samples have rare soil material pellets (probably oral) within the

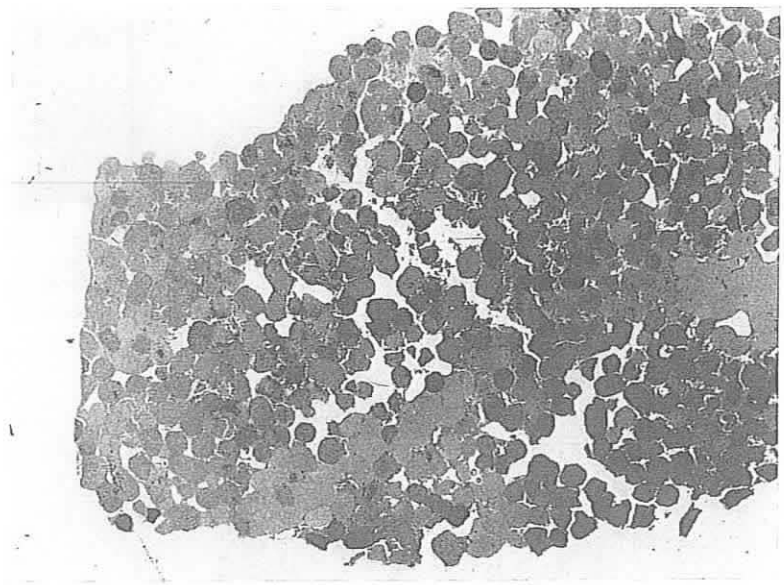


Figure 25. Class Ia material. Frequent anal pellets composed of type B organic material. *Porotermes adamsoni* — mudgut in tree. Frame length 4 cm. Plain light.

structural walls and single soil material pellets (probably oral) or single organic stained pellets (probably microarthropod droppings) occurring in the galleries. *Nasutitermes triodiae* hard core as above; outer mound may have very rare soil material pellets probably oral) within the structural walls; hard basal section with weaker lenticular fabric, less organic matter and the groundmass is zoned with organic rich areas resembling pedotubules surrounded by organic-deficient areas; some outer mound materials are intermediate between classes IIa and IIc, having a high proportion of clay-mineral plasma in the s-matrix which under crossed polarizers appears to be composed of spheroidal aggregates in the size range 10—20 $\mu$m. *Coptotermes acinaciformis* soil cap in which there are less frequent organic laminae and the lenticular fabric is not as well developed.

*3.2.2.2. Class IIb*

Composition: Soil material of type B (i.e. with a high proportion of clay-mineral plasma) with a moderate proportion or organic material occurring as relatively thick brown laminae of type B and nodules consisting of fragments of disrupted laminae of type B.

Fabric: Very porous, very weak masepic or ma-insepic porphyroskelic fabric with frequent irregular vughs. Occasional organic laminae and frequent organic nodules occur throughout the material. Lenticular fabric is generally absent or very weakly developed. Slightly distorted pellets consisting of soil material and probably of oral origin are common to frequent throughout (Fig. 21).

Species and variants: *Nasutitermes magnus* outer mound in which the organic laminae and nodules are mainly of type A, and recognizable pellets are rare. *Nasutitermes exitiosus* outer mound and soil cap but the latter may lack organic laminae. *Coptotermes lacteus* soil cap, one sample of the latter being an intergrade between classes IIb and IIc and having rare organic laminae and nodules, type C soil material, and occasional rounded vughs that may be interconnected.

Table 2 Micromorphological classes related to species and part of nest

| | | Mound | | | | | | | | Non mound | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Nursery | Hard Core | Bot-tom | Top | Inner | Outer | Soil Cap | Subter. Galleries | Carton | Mudgut | Unspec. Galleries |
| *Porotermes adamsoni* | (2) | | | | | | | | | | Ia | |
| *Mastotermes darwiniensis* | (1) | | | | | | | | | Ia | | |
| *Coptotermes acinaciformis* | (2) | Ic | | | | | | IIa–IIc | | | | |
| *C. lacteus* | (1) | Ib | | | | Ib | Ib | IIb | | | | |
| *Amitermes laurensis* | (3) | | IIa | | | | IIa | | | | | |
| *A. meridionalis* | (3) | | IIIa | | IIIa | | | | | | | |
| *A. vitiosus* | (3) | | | | | | IIc | | | | | |
| *A.* sp. | (1) | | | | | | | | | | | IIIa |
| *Drepanotermes rubriceps* | (3) | | | IIc | IIc | | IIa | | IIc | | | |
| *Microtermes nervosus* | (2) | | | | | | IIIb | | | | | |
| *Nasutitermes exitiosus* | (1) | Id | | | | Id | IIb–IIIb | IIb | | | | |
| *N. magnus–* | (3) | Id–IIIa | | | | | IIb–IIc | | | | | |
| *N. triodiae* | (3) | IIIa | IIa | IIa | | | IIa | | | | | |
| *Tumulitermes hastilis* | (3) | | | | | | IIc | | IIc | | | |
| *T. pastinator* | (3) | IIa | | | | | IIa | | | | | |

(1) Principal food — Dead wood
(2) Principal food — Living and dead wood
(3) Principal food — Grass

*3.2.2.3. Class IIc*

Composition: Soil material (with variable proportions of clay-mineral plasma) with very little organic material; where organic material is present it occurs as rather diffuse, indistinct broad laminae and/or nodules (approaching type A) that are organic rich rather than pure organic matter.

Fabric: Generally an undifferentiated fabric that approaches the bow-structure of Stoops (1964) as the diffuse laminae become more distinct. Masked argillasepic, masepic or inundulic porphyroskelic fabric, somewhat variable in porosity especially in regard to the frequency of irregular vughs. Distinct organic laminae are rare but the material may appear to have a fine lamination especially towards the walls of the galleries. Lenticular fabric is virtually absent. Pellets are not generally recognizable (Fig. 22).

Species and variants: *Drepanotermes rubriceps* subterranean galleries which are finely laminated showing moderately to strongly developed bow-structure. *Nasutitermes magnus* outer mound with rounded vughs cf. class IIb. *Tumulitermes hastilis* subterranean galleries with an s-matrix that under crossed polarizers appears to be composed of spheroidal aggregates in the size range 20—60 $\mu$m (Fig. 23) and lacking organic laminae and nodules; outer mound with a similar s-matrix with rare organic laminae and very weak lenticular fabric mainly confined to filled galleries. *Amitermes vitiosus* outer mound again with a very weak lenticular fabric mainly confined to filled galleries. *Coptotermes acinaciformis* soil cap in which the s-matrix shows occasional weakly developed rounded aggregates in the size range 15—40 $\mu$m and in which the organic laminae are broad and indistinct and the lenticular fabric confined to filled galleries.

### *3.2.3. Class III*

*3.2.3.0. General remarks*

Dominantly organic plasma with frequent skeleton grains and/or lenses of soil material low in organic material (Figs. 24).

Variations between samples in class III are due mainly to the presence or absence of lenses or 'cores' of soil material low in organic material, the composition of the organic material of the s-matrix, laminae and nodules, and the arrangement of the laminae.

*3.2.3.1. Class IIIa*

Composition: The organic material within the s-matrix laminae and nodules is of type A; frequent skeleton grains are scattered randomly throughout the mass of the material and if present, soil nodules are very rare.

Fabric: Usually inundulic porphyroskelic fabric with skew planes and vughs. Organic laminae are relatively abundant and generally increase in frequency towards the gallery walls where they occur in a crenulate fabric and where there are also restricted zones with lenticular fabric. Pellets are only recognizable in a distorted form within the lenticular fabric. This fabric has a number of characteristics in common with that of class IIa, but has a higher proportion of organic plasma and a weaker development of lenticular fabric.

Species and variants: *Nasutitermes triodiae* nursery. *Nasutitermes magnus* nursery, with masepic porphyroskelic fabric. *Amitermes meridionalis* top section of mound with a very low proportion of plasma in the s-matrix, broad indistinct organic laminae with skeleton grains scattered randomly throughout, frequent opaline silica bodies (phytoliths?) with rare faecal pellets in galleries. *Amitermes meridionalis* hard core of mound, with rare laminae in a weak lamellar fabric with weakly developed bow-structure. *Amitermes* sp., galleries under bark, as for *Amitermes meridionalis* hard core of mound.

*3.2.3.2. Class IIIb*

Composition: Organic plasma of type B containing randomly distributed skeleton grains with lenses of soil material with relatively lower organic material especially in areas away from the gallery walls.

Fabric: Lammellar fabric, consisting of organic laminae of type B, is well developed towards the gallery walls. The fabric is similar to that of class Ib but with a higher proportion of soil material with fabric comparable to class IIb i. e. insepic or argillasepic porphyroskelic fabric (Fig. 24).

Species and variants: *Nasutitermes exitiosus* outer mound, with strong crenulate fabric adjacent to gallery walls, common organic nodules of type B and maybe with welded or distorted pellets in galleries. *Microcerotermes nervosus* outer mound, with strongly developed lenticular fabric.

## 4. Discussion

Within the materials examined there is a wide range of materials and fabrics — at one extreme a single undifferentiated material such as the organic material found in *Porotermes* mudgut, (Fig. 25) and the dominantly mineral material found in the upper mound region of *Drepanotermes* (Fig. 22) to the other extreme, a multiplicity of materials including organic matter, faecal pellets and mineral soil material in complex fabrics such as that shown in Figure 19. In general the same species in different localities appears to construct particular parts of a mound with similar materials but the proportions may change considerably as shown by the outer mound materials of *Nasutitermes exitiosus* sampled at Para Wirra and Braidwood — the former is dominated by type B organic matter adjacent to the gallery walls with very minor pelletal mineral soil zones and the latter dominated by pelletal mineral soil with very minor type B organic material again adjacent to the gallery walls. Such changes in proportion of materials may be accompanied by changes in fabric as seen in the nursery materials from mounds of *Nasutitermes magnus* sampled at Warwick and Atherton — the former has a high proportion of organic material and lacks lenticular fabric whereas the latter has a high proportion of mineral soil and a lenticular fabric in part.

The organic material would appear to be the most significant in regard to interpretation of mound construction. Type A most commonly occurs as single laminae associated with lenticular fabric, as squashed faecal pellets in gallery fills, as organic nodules or diffusely through the plasma of the s-matrix, whereas type B most commonly occurs in parallel groups producing a lamellar or crenulate fabric, or alternatively in pellets or nodules. The characteristics of type A, viz. lack of tissue structures, almost complete lack of doubly refracting material and dominance of dark brown partly opaque substances suggest that it is more highly humified than type B (see Babel 1965). It may be that type A organic material has passed through the gut of the termite whereas type B has not. Alternatively if both have been passed through the gut this variation could be due to variable resistivity of materials to humification in the gut and/or variable efficiency of different species to humify material in the gut. Bal (1970) quotes organisms, e.g. Phthiracaridae (Acarina, Cryptostigmata) which have little to no ability to change colour or biochemical composition of food on passage through the gut. Since most described faecal material is dark brown to black it would seem reasonable to assume that most of the type A material above is of faecal origin, with the possible exception of the irregular nodules and some of the diffusely distributed organic material as found in bow-structure, which may be normal $A_1$ horizon soil material. According to Lee and Wood (1971a) the excreta

of termite species that do not habitually injest soil is usually darker than soil particles in the mounds. On the other hand there appears to be little micromorphological evidence for the origin of type B material (i.e. anal or oral) in the materials examined. However as micromorphological analysis of *Porotermes adamsoni* mudgut material[1]) (known to be of faecal origin) shows this to be composed of type B organic material (Fig. 25), it is accepted that laminae and pellets of this material are most likely anal. The organic laminae occurring either individually or as a component of lenticular, lamellar or crenulate fabric are most likely excrement since they are undoubtedly made from materials with a semi-liquid consistency which according to LEE and WOOD (1971a) is the consistency of most termite excrement.

The smaller single pellets and some of the larger pellets that occur singly or as welded units in galleries (Figs. 12 and 13), are droppings of arthropods. The dark flattened pellets as shown in Figure 14 obviously include much faecal material and are most likely termite droppings. The pellets shown in Figure 15 occurring within the structural walls of a mound are approximately 0.6 mm across, have a high proportion of clay-mineral plasma lacking dark organic pigment but may include occasional nodules of organic matter of type B. Such pellets do not appear to have passed through the gut but rather appear to have resulted from the reworking of a high clay-mineral plasma soil material and a gallery lining composed of type B organic material with a lamellar fabric. This species, *Nasutitermes exitiosus* in fact has been observed by LEE and WOOD (1971a) to use this method for expanding its mound by reworking the inside outwards, the new gallery walls being then lined with type B organic laminae, probably of anal origin. The distorted pellets, recognized as a component of lenticular fabric, usually consist of soil material without organic staining and are considered to be of oral origin.

In all these materials the greater proportion of skeleton grains are much smaller than the largest termite droppings (600 $\mu$m) but in many the maximum size falls in the range 1—2 mm while rock nodules 2.5 mm in diameter have been recorded in mounds of *Nasutitermes exitiosus*. Presumably these figures set an upper limit to the size of grains that can be carried in the mandibles. According to LEE and WOOD (1971b) it is the size of the workers that sets the upper limit to the size of particles that can be carried in the mandibles.

Class I materials completely lack dark brown type A organic laminae and nodules — the type A nodules present are very fine (7 $\mu$m) red isotropic fragments Class II materials are quite variable in this respect with nil to moderate amounts of type A organic material in the form of laminae or organic nodules which are often flattened faecal pellets occurring as gallery fill. Class III materials completely lack dark brown type A organic nodules but usually include thin type A organic laminae, the exception being *Amitermes meridionalis* which has galleries filled with flattened faecal pellets.

Apart from the fact that nursery sections tend to have the highest content of only slightly decomposed type B organic material, Table 2 reveals no relationship between fabric and particular parts of nests. However there appears to be some sort of a relationship between fabric and principal food, viz. that the grass-feeding species appear to build mounds mainly with soil materials with perhaps minor highly decomposed type A organic material whereas the wood-feeders tend to build mounds or nests mainly of slightly decomposed, type B organic material with minor soil component confined to outer soil cap if present.

Of the seven wood-feeding species all except *Microcerotermes nervosus* and *Amitermes* sp. build highly organic nurseries composed of class I material maybe with a thin capping usually of calss II material or less commonly, class III material. The notable feature of all these materials, with exception of one sample of an outer soil cap from a mound of

1) Sample provided by T. GREAVES, CSIRO, Division of Entomology.

*Coptotermes acinaciformis*, is a complete lack of type A organic material. Within the class I material, there occur variable proportions (very rare to common) of organic (type B) pellets of average size 300 $\mu$m, and within the class II materials there occur variable proportions (very rare to common) of pellets of soil material in the size range 400—600 $\mu$m. The carton material of *Coptotermes acinaciformis* shows many intergrades from pellets of organic matter (redder and more isotropic than the surrounding material) through elongated lens-shaped units to true laminae. All of which seems to suggest a construction method using pellets of 300 $\mu$m diameter consisting of fragmented birefringent, relatively undecomposed organic matter in nursery areas and pellets of 400—600 $\mu$m diameter consisting of soil material (mainly with a high proportion of clay-mineral plasma) in the outer layers. As stated previously these organic pellets are assumed to be of anal origin due to their similarity with known faecal pellets in a mudgut sample of *Porotermes adamsoni*, a tree-dwelling species. The soil material pellets show no signs of having passed through the gut, and are assumed to be of oral origin.

Among the grassfeeders, the nursery material is quite variable, varying from dominantly organic with *Nasutitermes magnus*, through co-dominant organic with *Nasutitermes triodiae*, to dominantly mineral soil with *Tumulitermes pastinator*, and the fabric has little in common apart from a crenulate fabric associated with gallery walls. The other mound materials are dominated by mineral soil but show the full range of fabrics described for class II materials.

## 5. Summary · Zusammenfassung

Sixty thin-sections (6 × 5 cm) of parts of nests of 14 species of termites from 18 different sites have been examined and the materials classified on micromorphological data. Three classes of nest materials are distinguished on the basis of the proportion of organic and mineral material present. Within each of these, subclasses are distinguished on patterns of voids (other than galleries) and the occurrence of organic nodules and laminae, pellets, lenticular, lamellar, and crenulate fabrics and bow-structure. These morphological classes are related to species, feeding habit, part of nest, and location of nest. An attempt is made to interpret these various micro-structural features and fabrics in terms of building habits.

**Mikrostrukturen einiger australischer Termitennester**

Sechzig Dünnschliffe (6 × 5 cm) von Nestteilen von 14 Termiten-Arten, von 18 Biotopen, wurden untersucht und die Materialien wurden auf Grund mikromorphologischer Daten klassifiziert. Drei Klassen von Nestmaterial wurden auf der Basis des Verhältnisses von organischem und mineralischem Substrat vorgestellt. Innerhalb jeder Klasse werden Subklassen nach der Art der Hohlräume (nicht Gallerien) und dem Vorkommen von organischen Verdickungen (nodules) und Plättchen (laminae), Kotballen, linsenförmigen, lamellösen und gewellten Gefügen und Bogenstrukturen unterschieden. Diese morphologischen Klassen werden zu den Arten, zur Ernährungsweise, zum Nestteil und zum Standort des Nestes in Beziehung gebracht. Es wird versucht, diese verschiedenartigen mikrostrukturellen Eigentümlichkeiten und Gefüge nach Bauweisen zu interpretieren.

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